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THE AMERICAN JOURNAL OF PSYCHOLOGY

Founded by G. STANLEY HALL in 1887

VOL. XX

JANUARY, 1909

No. 1

THE PSYCHOPHYSICS OF CLIMATE

By E. B. TITCHENER

I owe to Professor Cleveland Abbe a number of references to papers of psychophysical import, published for the most part in meteorological journals, which so far as I am aware have escaped the notice of experimental psychologists. Such further search as I have been able to make has brought to light other papers of like character, and I have no doubt that a systematic student of meteorological 'literature' would discover still more. I desire, however, in the present note, simply to call attention to a few points of importance, and to print a very tentative bibliography.

The 'method of classification' or 'method of the psychophysical series', which in theory goes back to Fechner's essay *Ueber ein psychophysisches Grundgesetz und dessen Beziehung zur Schätzung der Sterngrößen*¹, is usually referred, as a method of laboratory practice, to Ebbinghaus (1887) and Jastrow (1888).² I find, however, that as early as 1876 experiments were made by J. W. Osborne, of Washington, D. C., upon the classification of sensible temperatures.³ Osborne's method "consists in obtaining from a sufficiently large number of intelligent persons, their individual estimate of the sensible temperature for certain fixed hours in each day, and then deducing means from the whole record. . . . This was accomplished by conceiving the total range of sensible climatic temperature to be divided into twenty equal parts, counting upwards from the extreme of cold. To each of these divisions

¹*Abhandlungen d. kgl. sächs. Ges. d. Wiss.*, iv., 1859 [1858], 457-532. See my *Exper. Psychol.*, II., ii., 1905, 419.

²See my *Exper. Psychol.*, II., ii., 1905, 85, 89, 91.

³Determinations of Subjective Temperature, in *Proceedings A. A. A. S.*, 25 Meeting (August, 1876), 1877, 66 ff.

a descriptive expression was affixed conveying in as unambiguous a way as possible, the idea of a progressive elevation of temperature at every step. The observer, in the open air, and sheltered only from the direct rays of the sun, selects the expression which most nearly describes his appreciation of the sensible temperature at the time, and records, not the expression, but the number attached to it. From such records, means and generalisations can be obtained which increase in value as the observers increase in numbers, and gain experience". The scale of observations, as printed on the outside of the record-card, is as follows: 20 Intolerably hot; 19 Excessively hot; 18 Very hot; 17 Tolerably hot; 16 Very warm; 15 Decidedly warm; 14 Agreeably warm; 13 Mild and soft; then, after an interval, 12 Mild and fresh; 11 Quite fresh; 10 Very fresh; 9 Decidedly cool; 8 Very Cool; 7 Moderately cold; 6 Cold and fine; 5 Cold and sharp; 4 Very cold; 3 Bitterly cold; 2 Painfully cold; 1 Unbearably cold. A foot-note adds: "However qualified, these expressions must be understood to refer to equal gradations of sensible temperature only". Under the heading of 'Remarks' are given three scales of letters, which provide for a general characterisation of the weather in terms of wind, humidity and sunshine.

The results obtained from 25 to 35 observers over a period of 9 weeks from June to August are shown in tables of daily observations and means and of weekly means. The writer points out that, "as was to be expected, the observations do not always coincide for the same day and period [time of day]. This is due to the fact that the system at best is but approximate, that individuals differ in their estimates of temperature, and that living in different localities, some exposed to one wind, and some to another, they are not affected similarly. Nevertheless the means obtained from this large mass of somewhat crude material, have exhibited so remarkable a degree of consistency and harmony as to justify great confidence in the method, which certainly furnishes information relative to climate that has not been hitherto obtained". Unfortunately, no attempt is made in this paper to compare the subjective estimates of temperature with the ordinary meteorological records. What is significant, however, from the psychophysical point of view, is the writer's assumption (roughly verified by the facts) that the average educated man or woman is able to 'place' a given experience of climatic temperature upon a subjective temperature-scale made up of 19 equal sense-distances between the limits 'intolerably hot' and 'unbearably cold'.

Another and perhaps a still more striking instance of 'psychophysics by common sense' is found in two papers by W. F. Tyler, entitled respectively "A Scheme for the Comparison of

Climates"¹ and "The Psycho-Physical Aspect of Climate with a Theory Concerning Intensities of Sensation".² The writer's aim is to lay down a scale of some sort for the intercomparison of climates, as regards, *e. g.*, their bracing or relaxing character. "It has been assumed that the principal factors forming climate are some five in number", rainfall, soil, altitude, aspect, wind. These five may be reduced to the four: humidity, temperature, sunshine, pressure. And these, again, may practically be reduced to two: humidity and temperature. "It seems likely that temperature and humidity are so incomparably more important and of more effect than the others, that, eliminating these other comparatively unimportant factors, a law may be found (sufficient for practical purposes) connecting the sensation scale with temperature and humidity alone".

"The observations were made as follows: A number of persons of normal condition and regular habits were requested to estimate daily at noon the degree of 'hyther' on a scale of 0 to 10. The word hyther was introduced to indicate the sensation caused by a warm climate [the original observations were made at Shanghai], and supposed to be due to the combined effect of heat and humidity. *Ten* represents the very worst day an observer remembers to have experienced in Shanghai—hot, damp and enervating; while 0 represents an ideal summer's day—warm of course, but bright, brisk and bracing, when, suitably dressed, one suffers no discomfort from temperature and humidity". The hyther or 'hydrotherm' is thus taken as the unit of mugginess.

As to the possibility of a sensation scale, "it is maintained that the mind has an innate, but generally dormant, faculty of subdividing a sensation or emotion". "Many, if not most sensations, have instrumentally measurable conditions corresponding to them in their varying intensities, and the whole object of the writer's idea in regard to sensation scales generally is the establishment of the laws connecting equal differences of these sensations with the instrumental variations corresponding to them, and thereby enable (*sic*) the formation of scales in terms of instrumentally measurable quantities, the degrees of which correspond to equal differences of sensation". A terminology is then worked out. The innate faculty of the mind to graduate is termed indicativeness. "*Sensation* is the physiological effect, of which we are cognizant, of one or more physical causes. A *Sensation Scale* is a means whereby the

¹Journal of Balneology and Climatology, VIII, January, 1904, 17 ff.

²London, John Bale, Sons and Danielsson, Ltd. 1907. Reprinted from the *Journal of Tropical Medicine and Hygiene*, April 15, 1907. This second paper in large measure repeats the earlier essay of 1904.

intensity of a sensation can be named. A *Sensation Increment* is the minimum appreciable alteration in the intensity of a sensation. A *Physical Increment* is the amount of variation of the physical cause producing a sensation increment". Sensation increments are equal (1904, p. 23; 1907, p. 9) and may be summed up; the physical increment is "a variable quantity, and by analogy alone it might be assumed that it is some function of the intensity of the physical cause". "*Equal Differences of Sensation* are those which have the subjective effect of a similar degree of change".¹

Here surely is Fechner *redivivus*,—although Mr. Tyler has never heard of Fechner! The adoption of the just noticeable difference as the unit of sensory measurement; the doctrine that all just noticeable differences of sensation are equal; the contention that just noticeable differences (or other unit-differences of sensation) may be summed up; the standardisation of the sense-scale by reference to a corresponding stimulus-scale: all these things are commonplaces to the reader of the *Elemente*. The writer even vacillates, as Fechner does, between the notion that the single sensation is a measurable magnitude and the notion that it is merely the limiting term of a sense-distance; though it is fair to say that he seems to come nearer than his unknown master to the modern point of view. And indeed, if it were worth while, still other and more detailed parallels might be drawn between Mr. Tyler's positions and the traditional teaching of the psychophysicists.²

Fechner, as we all know, at first believed himself to be the discoverer of the law which is called by Weber's name, and only later found that he and Weber had, both alike, been anticipated. And he lays especial emphasis on the century-old classification of the fixed stars by visible magnitude. "Es

¹All of these definitions, except that of equal differences of sensation, are taken from the paper of 1904. In 1907 the sensation scale is defined as "a progression of stimulus intensities such that the differences of corresponding sensation between any consecutive pairs are equal to one another" (p. 9).

²The psychophysics of the paper of 1904 was worked out "quite independently," without any sort of technical knowledge of what the author, in his blindness, still calls "the little known subject of intensity of sensation" (1907, I). Before printing his second paper, Mr. Tyler had been made aware of Weber and Fechner, and had read Landois and Stirling's "Text Book of Human Physiology", Schäfer's "Text Book of Physiology", Mercier's "Psychology, Normal and Morbid", and Ladd's "Psychology, Descriptive and Explanatory". All, alas! secondary sources. He has, however, "seen no reason to alter anything he has written in consequence of what he has read", though he has "embodied in the paper [of 1907] extracts from the authorities named, with his own remarks concerning them",—remarks that are both instructive and amusing.

giebt . . . eine . . . Bewährung des Gesetzes an mehr als nur eben merklichen Unterschieden, zugleich die erste, die überhaupt für das Gesetz existirt, und zwar wiederum auf jenem hohen Beobachtungsfelde, dem die zuerst angeführten Bewährungen entnommen wurden, nämlich in der Schätzungsweise der Sterngrößen".¹ Mr. Tyler, now, finds outside confirmation of his 'sensation scales', of precisely the same kind. He appeals, first, to Beaufort's scale of wind force. This is a scale of twelve numbers introduced into the British Navy about the year 1805 by Admiral Sir F. Beaufort (1774-1857), for use in recording the apparent strength of the wind. The 0-point of the scale denotes calm, the 12-point a hurricane. "The general impression, even among meteorologists of eminence, appears to be that, because Captain Beaufort distinguished between wind forces according to the amount of sail his vessel [a full-rigged man-of-war] could carry, therefore the division of his scale was a mere arbitrary one. The writer's idea, however, is that, probably unconsciously, he selected twelve wind forces which differed from one another by an 'equal difference of sensation' and he in effect used the sails carried merely as identifying labels". Eventually, the velocities corresponding to Beaufort's numbers were ascertained, as the means of a large number of estimates; and Mr. Tyler shows that "these velocities are, with only one exception, within 1.5 miles, functions of the corresponding Beaufort numbers, being expressible by the formula:

$$v = 3 + 5n + \frac{n(n-1)(n-2)}{60}$$

where v is the velocity and n a Beaufort number. This indicates with certainty that the estimate of the wind force by Beaufort's numbers was not according to some arbitrary method, but that there is a definite relationship between the several intensities of sensation. For want of a better way of expressing it the writer says that sensations due to the different degrees of Beaufort's scale differ from one another by an equal degree of sensation". How Beaufort actually obtained his scale appears not to be certainly known; "several professional meteorologists" have accepted Mr. Tyler's interpretation (1907, p. 4).

A second bit of confirmatory evidence—which is, however, of a much more doubtful character, and upon which Mr. Tyler accordingly places less reliance—appears in the graduation of bath thermometers. "Certain bath thermometers are marked according to Dr. Forbes' Specification. Concerning who Dr. Forbes was and how he arrived at his graduation the writer

¹ *Elemente der Psychophysik*, i., 1889, 158.

has no knowledge.¹ It always appeared to him that these graduations were obviously empirical. A comparison, however, of them with those obtained [in the writer's own experiments with cold and warm water] by the method of physical increments shows a partial conformity in regard to differences which perhaps points to more than a mere coincidence''. Mr. Tyler, in fact, finds equal sense distances represented by 27, 10, 6 and 4 degrees F., where Forbes' Specification has Cold-Cool, 21 degrees; Cool-Temperate, 12; Temperate to Tepid, 9; and Warm to Hot, 7 degrees.²

It is time, however, that we returned to our hythers. With them it fared about as well as could have been expected. The several hyther numbers are plotted on diagrams, in which the temperatures are laid off along the axis of x and the differences between the wet and dry bulbs along the axis of y . In Mr. Tyler's own case, the numbers group themselves into fairly regular zones; in the case of four other observers the zones are distinctly indicated; in the case of seven observers we can say no more than that the higher and lower numbers are divided by a line, and that in all instances the line has approximately the same slope. If, however, the data from the eleven assistants are combined in a single diagram, the resulting curve is very similar to Mr. Tyler's; 'the remarkable conformity between these two curves tends to show that the estimates of No. 1 observer [the writer] were taken with considerable accuracy. There is rarely as great a difference as 1 [one hyther number] between them.' 'As far as any conclusion can be come to on

¹ The Dr. Forbes in question is no less a person than Sir John Forbes, F. R. S. (1757-1861), whom I am proud to claim, in virtue of his long residence in my native city, as a fellow Cicestrian. See *The Cyclopædia of Practical Medicine*, edited by J. Forbes, A. Tweedie and J. Conolly, i., 1833, art. Bathing, p. 245. Forbes merely says that his scale is "founded on practical indications". It is laid out, not in single values (as on current bath thermometers), but in ranges; cold 33-60, cool 60-75, temperate 75-85, tepid 85-92, warm 92-98, and hot 98-112 degrees F.

² At the risk of too much detail, I cannot refrain from mentioning that Mr. Tyler attempted to construct a subjective temperature scale by two different methods: that "of estimating relative intensities in respect to two standard intensities",—the method of the psychophysical series, or the method of equal sense distances; and that of deducing "the relative intensities by means of experimentally ascertained 'least observable differences'",—the method which has been modernised as the method of limits. "And now", he says, "is brought to light a disappointing fact. The two methods of forming a sensation scale result in two different scales". Not only, then, did Mr. Tyler invent two of the recognised metric methods of psychophysics, but in seeking to correlate their results he has found, in strictly orthodox fashion, the discrepancy that we connect chiefly with the name of Merkel. A step further, and we should have had him discussing absolute impression, and the *R*-error, and Merkel's Law!

the very limited data provided, it would appear that temperature and humidity are certainly the factors of paramount importance in our appreciation of climate, but that 'some other factor or factors occasionally have appreciable effect.' Mr. Tyler was unable to connect observations for pressure, wind or nebulosity with the irregularities in the hyther numbers. He offers the tentative formula:

$$H = \frac{d - 1.2(d - w) - 66}{3},$$

where H indicates hyther on a scale of 0 to 10 (indicates, that is, the degree of discomfort due to the mugginess of the day), and d and w represent respectively the readings of the dry and wet bulb thermometer. Since for comparatively high humidities d and w are approximately the same, the formula may be simplified to:

$$H = \frac{w - 66}{3},$$

and the degrees of discomfort are thus brought into direct relation to the wet-bulb readings.

It would be superfluous to print, in this *Journal*, a technical criticism of Mr. Tyler's views, methods and results. To the psychologist, the significant thing with him, as with Mr. Osborne, is the effort of psychophysical construction. But it is not superfluous, I hope, to urge the better acquaintance of the psychophysicist and the meteorologist. Experimental psychology has already begun, from its own point of view, the study of the weather: Dexter's *Conduct and the Weather* came out in 1899, and Lehmann and Pedersen's *Das Wetter und unsere Arbeit: experimentelle Untersuchungen über den Einfluss der meteorologischen Faktoren auf die körperliche und seelische Arbeitsfähigkeit* came out in 1907. Now we learn that the meteorologists have these many years been engaged, for their purposes and from their point of view, upon the problem of 'subjective climate' or 'sensible temperature'. The solution of that problem, however, demands a combination of the two techniques and of the two standpoints. I have no doubt that solution, at any rate in the rough, is possible with the means at hand. Something can be done by the mutual printing of essays and reviews in the professional journals, by the exchange of papers, by personal correspondence. But I should like to see some of the younger generation of climatologists pass through the drill of the psychological laboratory, and I should like to see some student of experimental psychology take up the meteorological problem. The running analysis of the titles given below in the bibliography may help to indicate precisely where that problem lies.—

Just as I am about to send the MS. of this note to the printer, I receive the *Zeits. f. Psychol.*, xlix., Heft 3-4, which contains an article by J. Plassmann on "Astronomie und Psychologie." It is clear that the technical 'literature' of astronomy offers to the psychophysicist a mine of unworked materials at least as valuable as those that I have found in the works upon meteorology. The extraction and refining of the metal, in both cases, will require time and labor; but it is greatly to be hoped that some interested student may undertake the task.

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1826. W. Heberden, An Account of the Heat of July, 1825; together with Some Remarks upon Sensible Cold. *Phil. Trans. Roy. Soc. Lond.*, 1826, pt. II, 69-74. [Suggests that the way to estimate 'sensible cold' would be to warm a thermometer (on the assumption that the radiating surface of the instrument is analogous to that of the body) "to a height something exceeding the natural heat of the human body, and then to observe at what rate the quicksilver contracted upon exposure to the air".]
1853. J. C. Houzeau, *Règles de climatologie*, pp. 59 f. [Proposes to take the readings of the wet-bulb thermometer as measures of sensible temperature.]
1860. C. Martins, Des causes du froid sur les hautes montagnes. *Annales de chimie et de physique*, 3d series, lviii., pp. 208-243. [Emphasises the importance, for subjective temperature, of the wind and of the direct action of the sun, in addition to the temperature of the air.—See also Du froid thermométrique et de ses relations avec le froid physiologique. *Montpellier Acad. Sci. Mém.*, IV., 1858-60, pp. 251-301. Conditions subjectives qui modifient la sensation du froid. *Brown-Sequard's Journ. de Physiol.*, III., 1860, 597-603.]
1873. J. C. Houzeau, *Patria Belgica*, 1 re partie, p. 12. [Again recommends the wet-bulb thermometer, and gives tables.]
1876. J. W. Osborne, On a New Meteorological Instrument. *Proceedings A. A. A. S.*, 24 Meeting (August, 1875), 1876, Part 1, Physics, 59-70. [Refers sensible climatic heat to the three factors: temperature of the air, relative humidity, and force or velocity of wind. Proposes to measure sensible temperature by the time required for a mass of water, heated to the temperature of the human body, and contained in a paper cylinder of special construction, to cool under varying conditions.]
1877. J. W. Osborne, Determinations of Subjective Temperature. *Proceedings A. A. A. S.*, 25 Meeting (August, 1876), 1877, 66-74. [The paper referred to in the text. The author, at the end, expresses the hope that he may be able, on a future occasion, to compare his subjective results with the readings of the instrument described in the previous year. I have not been able to find any such comparison.—See also *Bulletin of the Philos. Soc. of Washington*, ii., p. 63; *Smithsonian Miscellaneous Collections*, xx., 1881.]

¹For aid in the compilation of this bibliography I am especially indebted to the Messrs. Cleveland Abbe, Sr. and Jr., to the librarian of the Surgeon-General's Office, Washington, D. C., and to Professor R. de C. Ward, of Harvard University.

1879. G. Forbes, On Observations relative to the Temperatures to which the Human Body is Exposed. *Journal of the Scottish Meteorological Society*, N. S., V., 1880, Nos. 49-62, pp. 273-4. [Describes an instrument similar to that of Osborne, and devised for the same purpose.]
1882. A. Borius, *Les maladies du Sénégal*, Baillière, Paris. [I have not seen this work. According to Vincent, 1907, the author argues (pp. 124-240) that the depressing or relaxing character of tropical climates is due to excessive humidity. He proposes, but does not use, a sensation scale: 0 Very cold, 5 Indifferent, 10 Extremely hot. Intermediate degrees are not defined.]
1885. C. Abbe, Meteorology. In *Smithsonian Report* for 1883, 483-569. [Report of scientific progress during 1883, with bibliography. Declares that 'exhilarating' and 'depressing' weather may be regarded as functions of air temperature, wind, barometric pressure and relative humidity. Refers to Osborne: p. 491; advocates special observation of days in which the human organism experiences such special feelings as are defined by the expressions: close, oppressive, harsh, raw, penetrating, chill, mild, soft, soothing, invigorating, exhilarating, stimulating, balmy, gloomy, cheerful, nervous, restless.]
1887. C. Smart, The Thermometer as a Climatological Instrument. *Trans. Internat. Medical Congress, 9th Session*, Vol. V., pp. 172-178. [Determines the combinations of air-temperature and wind-velocity that produce, in the unit of time, the same drop of the thermometer (from 98.4° F.) as a given degree of cold in a calm atmosphere. Argues that the "cooling effect" or the "demand on the powers of the system" in the two cases is the same.]
1890. J. Vincent, La détermination de la température climatologique. Brussels, 1890. Reprinted from *Annuaire de l'Observatoire Royal pour 1890*. Abstract in *Ciel et Terre*, 10e année, 1889-1890, p. 515. [I have not seen this paper. According to Hann, pp. 43 f., "Vincent undertook an extended series of investigations in order to show the relation between the temperature of the exposed surface of the skin (T); the air temperature (t); the excess of the temperature as indicated by the actinometer over that of the air, in degrees (d); and the velocity of the wind in meters per second (v)."] He found the approximate formula:

$$T = 26.5^{\circ} + 0.3^{\circ} t + 0.2^{\circ} d - 1.2 v.$$
The degrees are C. According to Van Bebber, p. 133, Vincent established further a seven-degree scale of temperature sensation as follows: 1 Very hot, copious sweat, discomfort, T over 37.5°; 2 Hot, sweat, little or no discomfort, T 34.5°-37.5°; 3 Warm, no sweat, T 31.5°-34.5°; 4 Moderate, indifferent condition,—one may sit in the open air without an overcoat,— T 29°-31.5°; 5 Fresh, cold, but not unpleasantly cold to the hands,—one cannot sit in the open without a coat,— T 26°-29°; 6 Cold, unpleasant to the hands, T 22°-26°; 7 Very cold, unbearable to the hands and unpleasant to the face, T under 22°.]
1889. H. F. Blanford, *Climates and Weather of India, Ceylon and Burmah*, Macmillan & Co., London, p. 48. [Contrasts the oppressiveness of a humid Red Sea temperature of 90° with the dry hot-wind season of the upper provinces of India at a temperature of 112° to 118°, when the conditions, "if not exactly agreeable, are borne without serious inconvenience."]
1892. M. W. Harrington, Climate and Meteorology of Death Valley, California, *U. S. Dept. of Agriculture, Weather Bureau Bulletin*, No. 1, pp. 50. [Remarks, p. 23, that the "most interesting

form of humidity by which to judge of the comfort to be found in residence at a place" is the relative humidity. The low relative humidity of the valley, together with the large air-motions, causes evaporation to proceed with very great rapidity. Again, p. 30, "a good measure of the rigor of a climate is to be found in the mean daily range of temperature." The diurnal ranges are great in the valley, but are equalled and surpassed elsewhere.]

- 1892-3. A. Piche, Le déperditomètre. *Assoc. française pour l'avancement des sciences*, Session de 1892, i., 195; ii., 296-300. [Describes an instrument that should measure the volume of gas or alcohol consumed in maintaining for a definite length of time a known volume of water at a uniform temperature of 37° C. under varying meteorological conditions.—The description is repeated in the *Bulletin mensuel de l'Observatoire Carlier d'Orthez*, 7e année, No. 1, January, 1901.]

1894. M. W. Harrington, Sensible Temperatures. *Intern. Med. Mag.*, iii., August, 481-485. Also published separately, as paper read before the American Climatological Association, Washington, D. C., May, 1894: pp. 7, with Discussion and three Plates. Abstract in *Amer. Metl. Journ.*, July, 1895, 93-95. [Sensible temperatures depend on evaporation; and when evaporation takes place they are invariably lower than the shade temperatures given in meteorological tables. In actual practice, the temperature of evaporation is taken by means of a wet-bulb thermometer. The author gives illustrative charts of (1) the reduction of mean temperatures over the United States, for a given period, due to evaporation, and (2) the resulting sensible temperatures.]

1894. C. Abbe, Humidity. *Monthly Weather Review*, xxii., 407 f., 453 f., 496 f. [Note on wet-bulb or sensible temperatures, with references. Printed for the first time in Oct., 1894; reprinted, with slight modification and abridgment, till Octr. 1895, when doubt is cast upon the correlation. In xxiii., 368, we are told that "a complete expression for the relation between atmospheric conditions and nervous sensations is under consideration, but has not yet been obtained." See also Summary for 1895, xxiii., 491; the wet-bulb readings are given for "the sake of certain studies in Hygiene." In xxiv., Jan. 1896, 3 the statement is made that the sensation of temperature depends on the temperature of the air, its dryness, the velocity of the wind, and the suddenness of atmospheric changes, all combined with the physiological condition of the observer. A complete expression of sensible temperature has not yet been obtained. See also Summary for 1896, xxiv., 488.]

1895. W. J. van Bebber, *Hygienische Meteorologie*. Enke, Stuttgart, pp. 124-145. [Discussion of the "Hygienische Bedeutung der Wärmerscheinungen." Very hot temperatures are endurable, if the air is dry and, more especially, if it is in motion; a moist day is oppressive with a temperature of only 30° C. (p. 130). Dry-air baths do no harm at 80°, while steam-baths may be injurious at 50° or less (p. 136). The injurious effect of low temperatures is due to the cold, to the dryness of the air (ct. Hann, pp. 54 f.), and to a violent air-motion (p. 138); yet we are especially liable to take cold in damp, tropical climates and in a climate "in welchem nasskaltes und windiges Wetter vorherrscht" (p. 143). Heat-prostration is due mainly to air-temperature and humidity; windlessness also plays a part (p. 137).]

1895. C. Abbe, Sensible Temperatures. *Monthly Weather Review*, xxi., March, 93 f. [Historical note.]
1895. B. S. Pague, Sensible Temperatures, or the Effect of Heat on the Body in California. *Amer. Met. Journ.*, xii., No. 6, Oct., 1895, 196-198. [Equates wet-bulb readings with sensible temperatures. Applies this correlation to the climate of Death Valley, etc. Sunstroke is due to heat and humidity.]
1896. W. F. R. Phillips, Sunstroke weather of August, 1906. *Monthly Weather Review*, xxiv., Novr., 409-413. [Besides heat, "evidently there must enter into the case another factor, namely, the accommodation of the individual to average physical environment, or the climatic equation."]
1896. W. F. R. Phillips, Sunstroke in California and Arizona. *Monthly Weather Review*, xxiv., Dec., 454-456. [These sunstrokes are "not caused by the traditional high relative humidity." References.]
1896. W. F. R. Phillips, Sensible Temperature. *Trans. Amer. Climatol. Assn.*, xii., 16-25. [Opens with an historical review of the subject. The writer correlated Osborne's subjective results with the synchronous meteorological observations, but "was unable to discover more than a very general agreement." He admits, nevertheless, that the uniformity of the records "does appear to suggest something more than accident." He discusses "the principal factors concerned in the determination of temperature sensation" and shows incidentally "why failure (to establish an instrumental register of sensible temperature) has so far been inevitable."]
1896. W. L. Moore. Some Climatic Features of the Arid Regions. *U. S. Dept. of Agriculture, Weather Bureau*, pp. 19, with 5 Plates. Communication to National Irrigation Congress, 5th annual session, Phoenix, Ariz., Decr. 15-17, 1896. ["The meteorological instrument that registers the temperature of evaporation and thus in a great measure the actual heat felt by the human body, is the wet-bulb thermometer." On Sept. 20, 1895, instructions were issued "to the observers of the weather service to begin the telegraphing from observation stations of the readings of the wet-bulb thermometer, more popularly known as the 'sensible' temperature. This is about the temperature felt by animal life." Charts are appended, showing the distribution of average actual and sensible temperatures over the United States.]
1896. W. A. Glassford, Why Summer in the Apparently Hot Arid Region is Comfortable. *Monthly Report, Oregon State Weather Service*, Jan., 1896, 23-29. [Equates 'sensible temperature' with the reading of the wet-bulb thermometer.]
1896. I. M. Cline, Influences of Climatic Conditions and Weather Changes on the Functions of the Skin. *Proc. Texas State Med. Assn.* Reprint, pp. 8, with a Plate. [Considers the functions of the skin, as influenced by weather changes and climatic conditions, under the headings of Secretion and Excretion, and Regulation of the Evolution of Heat. Both sets of functions are affected mainly by temperature and absolute humidity. The influence of these climatic factors is discussed in detail for the six types of climate in the United States: low damp warm, low damp cold, high dry, between low damp warm and low damp cold, between low damp warm and high dry, and between low damp cold and high dry.]
1897. W. F. R. Phillips, Clothing and Temperature. *Monthly Weather*

- Review*, xxv., May, 200-201. [Thermometrical observations, paralleled by estimate of subjective sensations. References to Rubner and van Bebbler.]
1897. M. Rubner und V. A. Lewaschew, *Archiv f. Hygiene*, xxix., pp. 1 ff. Abstract in *Meteorologische Zeitschrift*, xv., 1898, pp. 148 f. [I have seen only the abstract of this paper. It contains a report of experiments on the human subject, carried out in the respiration chamber. At low temperatures, 14-15° C., dry air is more comfortable than moist. Between 24° and 29° dry air appears cooler than moist; high temperatures are not uncomfortable if the air is very dry; visible sweat begins at 29° with a relative humidity of 22%. A relative humidity of 96% makes a temperature of 24° unendurable for any length of time. Evaporation (loss of water-vapor) is a continuous function of temperature both in dry and in moist air, but the course of the function varies very considerably with the relative humidity.]
1898. C. Abbe, Sensible Temperatures and the Curve of Comfort. *Monthly Weather Review*, xxvi., August, 362 f. [Suggests that diagrams be prepared, with a vertical scale of relative humidities from 0 to 100 and a horizontal scale of air-temperature from minus 10 to 100, and that the observer make a record whenever he feels like saying: "Well, this weather is just perfect."]
1899. C. Abbe, Sensible Temperatures. *Monthly Weather Review* xxvii., 18. [Brief comment on a suggestion in the *N. Y. Times* that the Weather Bureau "combine the figures indicating temperature, humidity and velocity of the winds into a single figure that would express just what people mean when they say and feel that the weather is hot or cold."]
1899. A. Lancaster, *De la manière d'utiliser les observations hygrométriques*. Rapport lu au Ve Congrès International d'Hydrologie, de Climatologie et de Géologie Médicales à Liège, 1898. Vaillant-Carmanne, Liège, 1899. [A comparative study of the combined effect of air-temperature and relative humidity at Brussels and at Vivi in the Congo Free State. The author sought to determine, in calm weather at Brussels, what combinations gave certain high temperatures, in his own case, an oppressive feeling of heat. He gives a numerical table of results. According to Tyler, 1907, 31, "Lancaster's oppression curve coincides very closely with the position which the curve for Hyther 1 would occupy. Now Hyther 1 is a condition when very lightly dressed in a hot climate one begins to feel discomfort. The same condition in Belgium experienced by an observer with heavy European clothing might well be said to be oppressive."]
1900. E. G. Ravenstein, The Geographical Distribution of Relative Humidity. In *Report of 70th Meeting of Brit. Ass. Adv. Sci.*, 817-818. [In temperate weather we can bear great humidity with equanimity, while the same degree of humidity accompanied by great heat may be unbearable. The writer maps the earth according to sixteen hygrothermal types of climate.]
1903. J. Hann, *Handbook of Climatology. Pt. i., General Climatology*. Translated by R. de C. Ward. New York, The Macmillan Co., 1903. pp. 43-46, 82 f. [Brief review of previous work on sensible or subjective temperature. The temperature which we actually experience depends upon air temperature, air movement, insolation and the humidity of the air. "In hot climates, and also in the summer of middle and higher latitudes, when the body is usually covered with perspiration, the temperature which is actually felt depends to a great extent upon the dry-

- ness of the air, or, to put it more plainly, upon the reading of the wet-bulb thermometer. . . . In the case of hot climates it would be advisable to include, among the climatic elements, the readings of the wet-bulb thermometer as a convenient index of the degree of heat which is actually felt by the human body". Refers critically to Abbe's proposal of 1883 (to classify days as harsh, raw, mild, etc.) and to Osborne's sensation scale of 1876. States that both very hot (p. 45) and very cold (pp. 54 f.) climates are more endurable when the air is dry.]
1904. W. F. Tyler, The Sensation of Discomfort. *Monthly Weather Review*, xxxii., 217. [Letter written from Shanghai, communicated by the editor, who adds comments on the writer's Scheme for the Comparison of Climates, and refers to Osborne. The editor remarks that the use of the wet-bulb reading as a measure of sensible temperature has "long since been given up."]
1904. W. F. Tyler, A Scheme for the Comparison of Climates. *The Journal of Balneology and Climatology*, viii., January, 1904, pp. 17-44, with plates. Not offprinted: price of number 2/-. [Paper referred to in the text.]
1904. R. de C. Ward, "Sensible Temperatures." *Bulletin of the American Geographical Society*, xxxvi., no. 3, 129-138. [Summary of factors concerned in sensible temperature. General review of work done, with appended bibliography.]
1906. R. Börnstein, *Leitfaden der Wetterkunde*, 2d ed., Braunschweig, p. 48. [Emphasises the importance of relative humidity for sensible temperature.]
1907. W. F. Tyler, Hythers and the Comparison of Climates. *Monthly Weather Review*, xxxv, June, 267 f. [Letter written from Shanghai in 1905, briefly discussing the 'comfort curve', the use of hythers, etc. The editor appends a bibliography.]
1907. W. F. Tyler, The Psycho-Physical Aspect of Climate with a Theory concerning Intensities of Sensation. London, John Bale, Sons & Danielsson, Ltd. Pp. 45, with plates. 5/-. Reprinted from the *Journal of Tropical Medicine and Hygiene*, April 15, 1907. [Paper referred to in the text.]
1907. J. Vincent, Nouvelles recherches sur la température climatologique. *Annales météorologiques* de l'Observatoire royal de Belgique, année 1907, nouvelle série. In extract, pp. 120. Abstracts in *Ciel et Terre*, xxviii., 1907, p. 25; *Annuaire météorologique* de l'Observatoire royal, 1908, p. 462. [In this paper Vincent modifies his formula of 1890 to read (with the omission of the d -values, which are discarded as empirical only):
- $$T = 30.1 + 0.2t - v \quad (4.12 - 0.13t).$$
- This formula "permet de calculer la température de la peau à l'ombre, lorsque l'on connaît la température de l'air et la vitesse du vent. On ne doit y recourir que lorsque t est supérieur à 17".—The most important point of the paper, however, is the ruling out of humidity as a factor of sensible temperature, under the conditions of the author's observations. His general conclusion reads: "lorsque la température superficielle de la main de l'homme est inférieure à celle qui provoque la production de sueur visible, ce qui est le cas le plus fréquent dans les climats tempérés, l'humidité de l'air n'a aucune influence sur notre sensation thermique et ne doit pas être considérée dans l'étude de cette sensation." And he writes in detail: "l'humidité de l'air . . . n'a aucune influence sur la température superficielle de notre corps, dans les conditions atmosphériques

ou nous avons opéré. . . . Le thermomètre mouillé, même immobile, suit bien les fluctuations de l'humidité; il devrait en être de même de la surface de notre corps, si cette surface était réellement comparable à un linge mouillé; mais qui ne voit qu'en général elle ne l'est pas? . . . La capacité de l'air ambiant pour la vapeur d'eau, capacité que la chaleur propre du corps élève et empêche de devenir nulle, est toujours suffisante, quelle que soit l'humidité relative, pour vaporiser immédiatement et complètement l'eau qui atteint la surface de notre corps. Lorsque la température de la peau vient à s'élever suffisamment sous l'action des influences atmosphériques, les glandes sudoripares deviennent très actives et déversent à la surface de la peau la sueur qu'elles ont secretée abondamment. Alors seulement notre corps peut être comparé jusqu'à un certain point au thermomètre mouillé, puisqu'il s'y accomplit une évaporation dans le sens habituel du mot, sur l'activité de laquelle l'humidité de l'air doit, cette fois, exercer une influence. Il ne faudra, en tout cas, jamais perdre de vue que notre corps a sa chaleur propre, ce qui constitue une différence importante avec le thermomètre mouillé. . . . D'ordinaire, notre peau ne peut être assimilée à un linge mouillé: cela est clair, puisqu'elle est presque parfaitement sèche. On raisonne pourtant à son propos comme si elle était toujours couverte de sueur. . . . La température de la peau mouillée est notablement inférieure à celle de la peau sèche; elle est, par contre, supérieure, et de beaucoup, à celle du thermomètre mouillé; les différences sont, du reste, loin d'être constantes." Vincent further discusses, with approval, Heberden's indirect method, and gives a bibliography of previous work, with critical notes. He advises that, whatever form of objective method be adopted, the observer should append to his records a statement of the subjective temperature in the terms 'very hot', 'hot', 'warm', 'mild', 'cool', 'cold' and 'very cold.' This scale may be roughly standardised as follows: Very hot, 37.5° and over; Hot, 34.5° to 37.4°; Warm, 32.4° to 34.4°; Mild, 27° to 32.3°; Cool, 26.9° and under. The point of transition from Cool to Mild is uncertain; the points of transition from Cool to Cold and from Cold to Very cold are still more uncertain. These determinations have, however, little practical importance, as we meet cold weather by appropriate clothing.]